REMOTE SENSING AND DEVELOPMENT OF ANNOTATED AERIAL PHOTOGRAPHS AS MASTER SOIL PLANS FOR PROPOSED HIGHWAYS

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BY

R. D. MILES

JHRP

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Final Report

REMOTE SENSING AND DEVELOPMENT OF ANNOTATED AERIAL PHOTOGRAPHS AS MASTER SOIL PLANS FOR PROPOSED HIGHWAYS

TO: J. F. McLaughlin, Director
Joint Highway Research Project

July 16, 1970

File No.: 1-4-21

FROM: Harold L Michael, Associate Director
Joint Highway Research Project

Project No.: C-36-32U

The attached report entitled "Remote Sensing and Development of Annotated Aerial Photographs as Master Soil Plans for Proposed Highways" completes Phase C of the project entitled "Annotated Aerial Photographs as Master Soils Plans." This report was prepared by Professor Robert D. Miles of our staff using the material prepared by Dr. H. T. Rib and Dr. M. G. Tanguay.

It is concluded that color aerial photography is the best and most reliable source of information for the interpretation of soils and soil conditions. It is recommended that personnel be trained to develop large scale master soil plans on color aerial photographic base maps.

The report is submitted to the Board for the record and for acceptance as fulfillment of the objectives of the research.

Respectfully submitted,

Harold L. Michael
Associate Director

HLM:ms

cc:
F. L. Ashbaucher
W. L. Dolch
W. H. Goetz
W. L. Grecco
M. J. Gutzwiller
G. K. Hallock
M. E. Harr
R. H. Harrell
V. E. Harvey
M. L. Hayes
E. M. Mikhail
R. D. Miles
C. F. Scholer
M. B. Scott
W. T. Spencer
H. R. J. Walsh
K. B. Woods
E. J. Yoder

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by

Robert D. Miles, P. E.
Professor, School of Civil Engineering

from research by

Dr. Harold T. Rib
Bureau of Public Roads
Washington, D. C.

and

Dr. Marc G. Tanguay
Ecole Polytechnique
Montreal, Quebec

Joint Highway Research Project
Project: C-36-32U
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and the

U. S. Department of Transportation
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The opinions, findings and conclusions expressed in this publication are those of the authors and not necessarily those of the Bureau of Public Roads

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July 16, 1970

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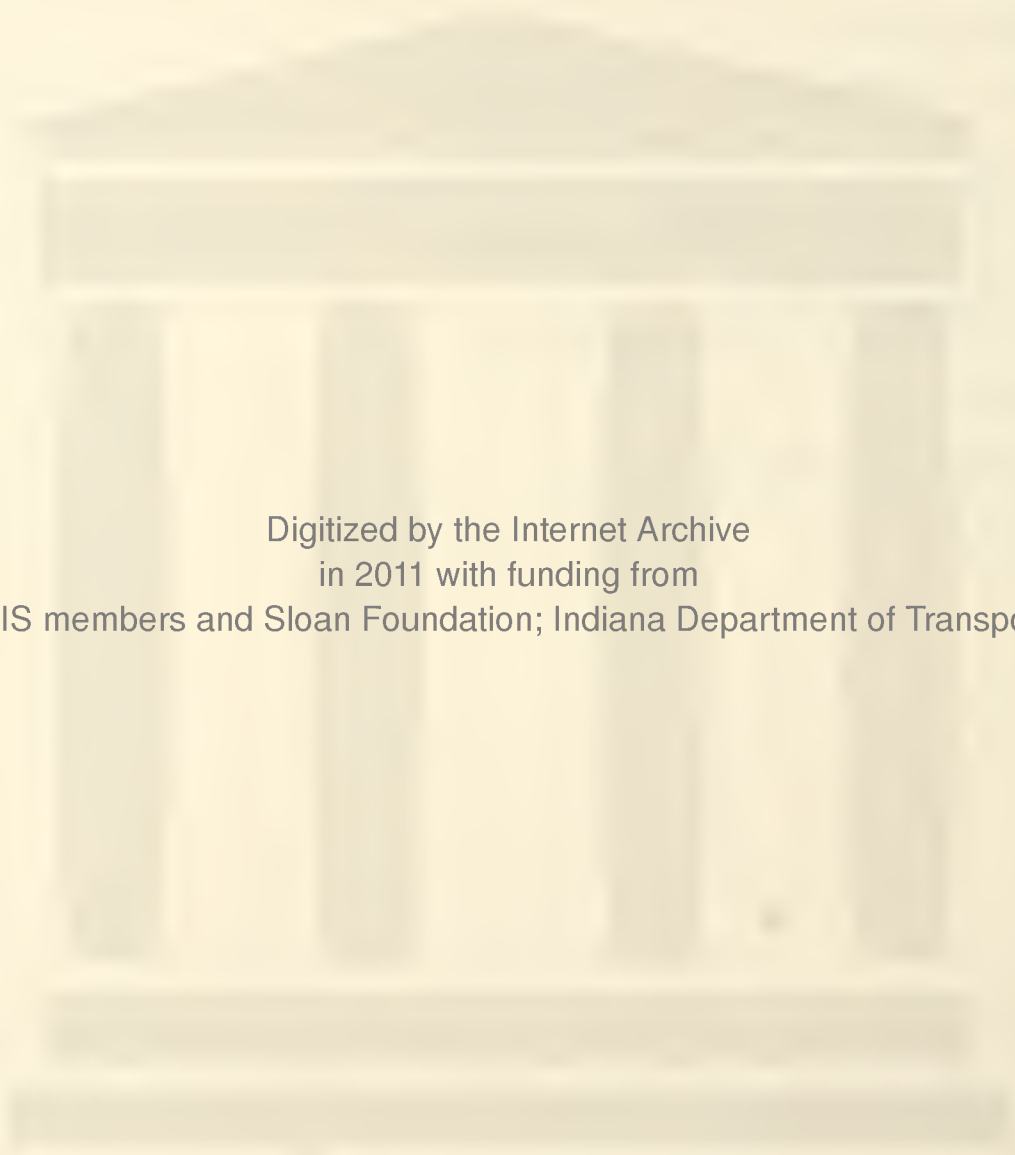

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ABSTRACT

Two comprehensive studies were made at Purdue University on the application of remote sensing systems to the development of master engineering soil plans. The remote sensing systems evaluated in the course of this research consisted of aerial photography, infrared imagery, side-looking airborne radar imagery and multispectral imagery. The multispectral analog data were used in conjunction with a digital computer to semi-automatically produce thematic maps and statistical analysis of reflectance of surfaces. Inference techniques were used to evaluate the photography and imagery.

It is concluded that in areas of low relief (300 feet or less) a color aerial photographic mosaic properly annotated is an excellent master engineering soil plan. An annotated black and white mosaic is also good but it is not as complete as a color mosaic relative to environmental conditions. Multispectral imagery is a research tool for investigations of semi-automatic mapping of reflectance from surfaces. Limited data are available on the significance of reflectance from soil surfaces.

Areas of high relief differences require the acceptance of perspective distortions on mosaics or photogrammetric compilation of thematic maps. For most engineering site selection and design studies, the perspective distortions of aerial photography are acceptable. The total view of the terrain and the soil environment shown on annotated color aerial photographs is more important than geometric accuracy.

INTRODUCTION

The use of black and white aerial photographs and deductive reasoning techniques of interpretation of engineering soils and soil conditions were developed at Purdue University around 1940 (5). Since then other remote sensing systems have been developed.

Two in-depth studies were made investigating the application of remote sensing systems to the evaluation of soils and soil conditions for highway engineering purposes. The first study was made during the period April 1965 to January 1967. The report on this phase was prepared by Harold T. Rib and was entitled:

> "An Optimum Multisensor Approach for Detailed Engineering Soils Mapping", 406 pages (9).

The second study was made during the period January 1967 to June 1969. The report on this phase was prepared by Marc G. Tanguay and was entitled:

> "Aerial Photography and Multispectral Remote Sensing for Engineering Soils Mapping", 308 pages (11).

These projects were a part of a comprehensive research proposal called "Annotated Aerial Photographs as Master Soil Plans for Proposed Highways". The research was conducted by the Airphoto Interpretation and Photogrammetry Laboratory, Joint Highway Research Project, School of Civil Engineering, Purdue University. The research was financed by highway user taxes administered by the Bureau of Public Roads, Federal Highway Administration, and the Indiana State Highway Commission. The research project was initiated on April 20, 1965 and was terminated on June 30, 1970. The budget for the 5½ year project was $77,800.00. In addition, the Indiana State Highway Commission expended about $6,350.00 for various types of aerial photography over four test areas.

The following publications, in addition to the two reports referenced above, resulted from this research project:

(1) "Multisensor Analysis for Soils Mapping" by Harold T. Rib and Robert D. Miles, Special Report 102 (1969), Highway Research Board, (Purdue University Engineering Reprint CE 266).

(2) "Automatic Interpretation of Terrain Features" by Harold T. Rib and Robert D. Miles, Photogrammetric Engineering, February 1969.

(3) "Automatic Technique for Abstracting Color Descriptions from Aerial Photography" by J. Gourley, H. T. Rib and R. D. Miles, Photographic Science and Engineering, January-February 1968. (Purdue University Engineering Reprint CE 248).

(4) "Multispectral Imagery and Automatic Classification of Spectral Response for Detailed Engineering Soils Mapping" by M. G. Tanguay, R. M. Hoffer and Robert D. Miles, Proceedings Sixth International Symposium on Remote Sensing of Environment, University of Michigan, October 13-16, 1969.

(5) "Multispectral Data Interpretation for Engineering Soils Mapping" submitted and approved for publication, Highway Research Board, January 1970.

The remote sensing systems evaluated in the course of this research consisted of aerial photography, infrared imagery, side-looking airborne radar imagery and multiband imagery as shown in Figure 1. An attempt

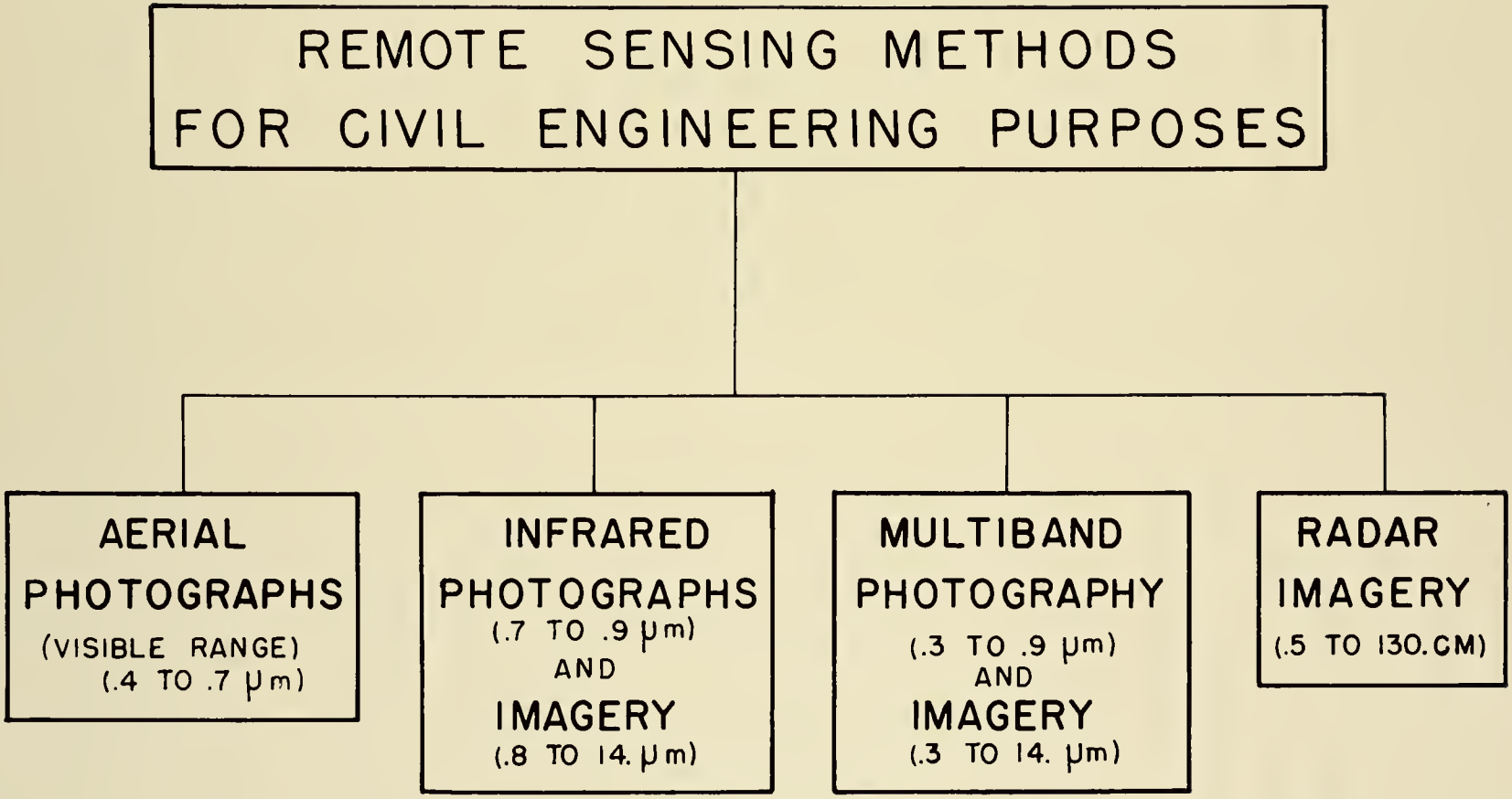

REMOTE SENSING METHODS
FOR CIVIL ENGINEERING PURPOSES
AERIAL
PHOTOGRAPHS
(VISIBLE RANGE)
(.4 TO .7 μm)
INFRARED
PHOTOGRAPHS
(.7 TO .9 μm)
AND
IMAGERY
(.8 TO 14. μm)
MULTIBAND
PHOTOGRAPHY
(.3 TO .9 μm)
AND
IMAGERY
(.3 TO 14. μm)
RADAR
IMAGERY
(.5 TO 130. CM)

FIGURE 1.

was made to achieve a multisensor approach whereby all systems would be operating over a short period of time on a given day but this was not accomplished. The nearest approach to a multisensor study was achieved when aerial photography and multispectral imagery was obtained on the same date. A summary of aerial photography and imagery obtained during the study is presented in Table 1. Sites I, II and III are located in Tippecanoe and Warren counties in the State of Indiana. The sites were selected by Rib and were relatively small areas with glacial, eolian and alluvial soils. Site IV was along a proposed highway and extended about 70 miles from Indianapolis southwestward through Bloomington to Bedford, Indiana. This site contained a variety of sedimentary rocks and residual soils as well as some glacial and alluvial soils. As shown in Table 1, the most complete coverage of sites I, II and III was obtained in May 1966 and of site IV on April 28, 1967.

The aerial photography for the entire project was obtained by the Photogrammetry and Reproductions Section, Office of Technical Services, Indiana State Highway Commission. In all instances they used a WILD RC-8 camera with a 6-inch lens appropriately filtered according to the film manufacturer's specifications (13). The personnel of the Photogrammetry Section gained considerable experience in the taking and processing of the various film types and performed an invaluable service to the success of the research project.

The multispectral imagery for the project was obtained under contract by personnel of the Infrared and Optical Sensor Laboratory, Institute of Science and Technology, University of Michigan with permission from the United States Army Electronics Command. On phase

TABLE 1. AERIAL PHOTOGRAPHY AND IMAGERY DATA

Date	Indiana Site	Scale	B&W	BI	CP or CN	CI	Multi-Spectral	IR	SLAR
May 13, 1965	I,II,III	1/10,000			X			X	X
July 1, 1965	I,II,III	1/10,000 & 1/4,000	X	X	X			X	X
July 26, 1965	I,II,III	1/10,000 & 1/4,000			X			X	
Sept. 1, 1965	I,II,III	1/10,000 & 1/4,000	X		X	X			X
Sept. 14, 1965 and Oct. 7, 1965		1/100,000							X
Oct. 25, 1965	I,II,III	1/10,000 & 1/4,000	X	X	X	X			
May 2-6, 1966	I,II,III	1/24,000; 1/10,000; 1/4,000	X	X	X	X	X	X	
June 1-2, 1966	I,II,III	1/4,000	X					X	
April 11, 1967	IV	1/12,000	X						
April 28, 1967	IV	1/6,000			X		X	X	
May 18-25, 1967	IV	1/6,000	X	X	X	X			

B&W - black and white negative film, BI - black and white infrared negative film, CP - color positive reversal film, CN - color negative film, Multispectral - narrow visible and infrared imagery, IR - thermal infrared imagery, SLAR - side-looking airborne radar imagery.

one of the project, as reported by Rib, 18 channels (1-UV, 12-Visible, 5-IR) were recorded. On phase two, 15 channels (1-UV, 12-Visible, 2-IR) were recorded on magnetic tape and reproduced as imagery.

The infrared imagery over sites I, II and III was obtained in the 4.5-5.5 micrometer and 8-14 micrometer spectral bands by personnel of the Intermountain Forest and Range Experiment Section, Northern Forest Fire Laboratory, United States Forest Service. Arrangement for and sponsorship of the flight was made by personnel of the Bureau of Public Roads, Federal Highway Administration, United States Department of Transportation.

The side-looking airborne RADAR (SLAR) imagery of sites I, II and III was obtained by personnel of the Avionics Laboratory, Wright-Patterson Air Force Base. The imagery was secured in conjunction with a NASA sponsored project with the Laboratory on Applications of Remote Sensing at Purdue University. The LARS group and agencies working with this group contributed a considerable amount of photography and imagery to phase one of the project. The computer programs developed by personnel at LARS for statistical evaluation of multichannel reflectance data were used extensively in phase two of the project (14).

Rib in his project report presented a rather complete summary of the basic energy considerations of the multisensor approach to the evaluation of materials at the earth's surface (9). He also summarized the previous (prior 1966) investigations made by soils engineers, geologists and others interested in earth materials. Tanguay updated (to 1969) the investigations made in remote sensing of the soil environment, and he explained the classification of solar reflectance by the use of multispectral information and a digital computer (11).

Tanguay also summarized the available information on the development of engineering soils maps for highway planning and design purposes using aerial photography as a source of information on soil distribution and soil condition.

PURPOSE AND SCOPE

It is the purpose of this report to summarize the findings of this entire research effort. The findings are pertinent as they pertain to the development of annotated aerial photographs as master soil plans for highway planning, design and construction. The master soil plans developed by airphoto interpretation techniques and supplemented with field sampling on a statistical basis should assist in determining unstable or unique soil conditions that require analysis for special design or special construction techniques.

This report is organized on the basis of types of aerial photography to include black and white, infrared, color and color-infrared and types of imagery to include infrared, side-looking airborne RADAR and multispectral imagery. The details on how the photography and imagery are obtained, the factors that influence the reflectance recorded and the technique of interpretation are discussed in the reports by Rib and Tanguay (9, 11).

AIRPHOTO INTERPRETATION AND REMOTE SENSING

The technique of airphoto interpretation is based on the analysis of pattern elements (5). The pattern elements consist of elements of form and elements of tone or color produced by reflectance (7).

The elements of form are three dimensional. They consist of topographic form, drainage form, erosional form and man-made forms. The topographic form is the configuration of the surface in both the uneroded and eroded condition. The drainage form is the plan arrangement and depth of development relative to base level of streams and all their tributaries within the topographic form. The erosional form is the shape and gradient of the gullies and rills that form after sheet erosion occurs on the uneroded topographic form. Man-made forms are unique shapes for living, communication and control of the environment. The evaluation of the three dimensional elements of form is both quantitative and qualitative. For example, the rolling topographic form of a ridge moraine has more significance relative to coarseness of the parent material if local relief is less than 30 feet or greater than 30 feet. The greater the local relief difference on moraines the more coarse-textured are the soils. Only aerial photography of the time-lapse type of those shown on Figure 1 has the capability of recording three dimensional forms.

The elements of tone or color are two dimensional. In aerial photography they consist of the reflectance of solar energy from bare soil or rock surfaces, various vegetative clusters and surfaces, or various man-made surfaces. The elements of tone or color used in airphoto interpretation are restricted to the visible and near infrared wavelengths (0.40 to 0.90 μm) of the electromagnetic spectrum as shown in Figure 2. Airphoto interpretation is therefore more restrictive than the broader field of remote sensing which includes infrared emittance and microwave reflectance.

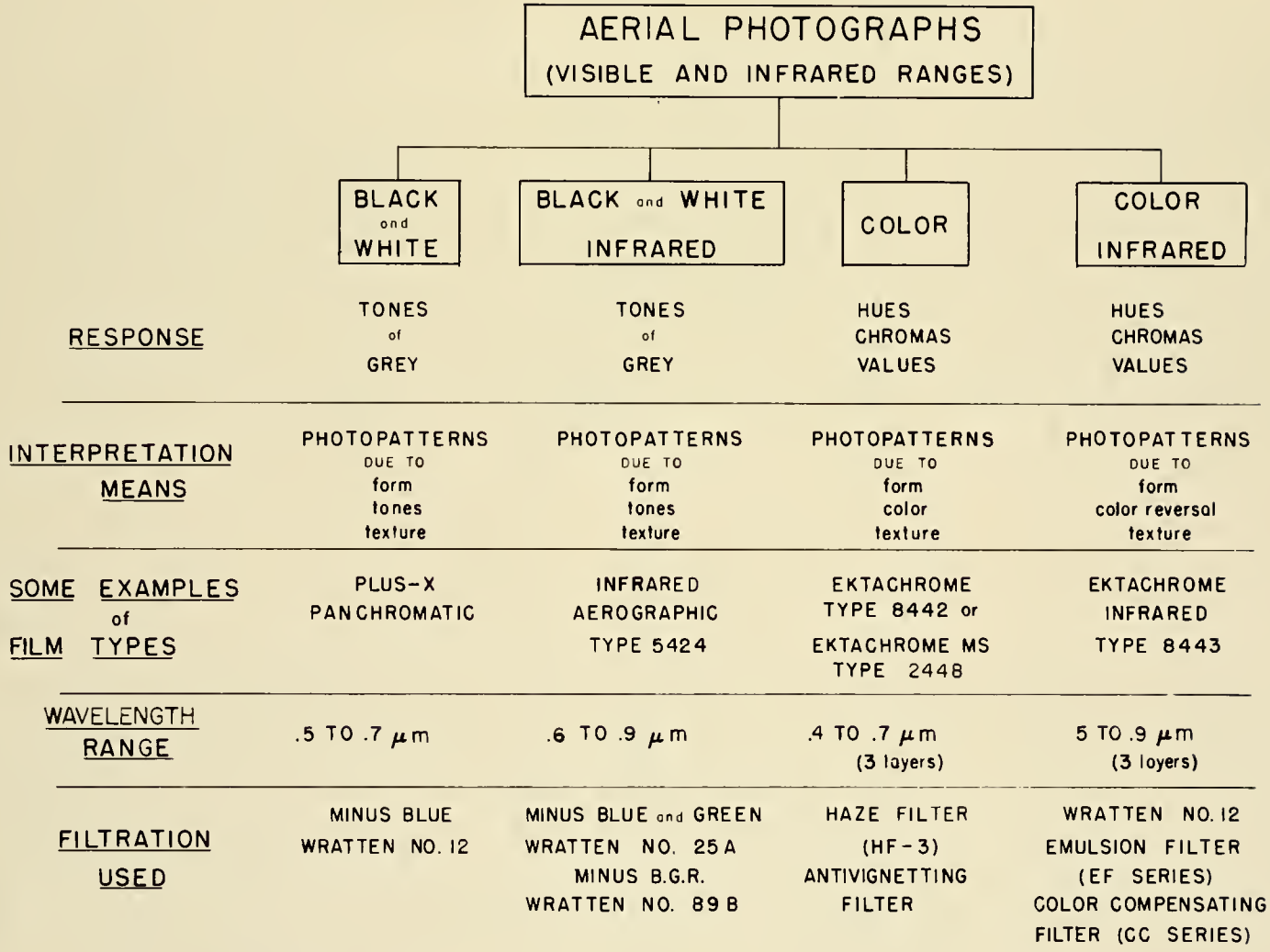

AERIAL PHOTOGRAPHS
(VISIBLE AND INFRARED RANGES)
BLACK and WHITE
BLACK and WHITE INFRARED
COLOR
COLOR INFRARED
RESPONSE
TONES of GREY
TONES of GREY
HUES CHROMAS VALUES
HUES CHROMAS VALUES
INTERPRETATION MEANS
PHOTOPATTERNS DUE TO form tones texture
PHOTOPATTERNS DUE TO form tones texture
PHOTOPATTERNS DUE TO form color texture
PHOTOPATTERNS DUE TO form color reversal texture
SOME EXAMPLES of FILM TYPES
PLUS-X PANCHROMATIC
INFRARED AEROGRAPHIC TYPE 5424
EKTACHROME TYPE 8442 or EKTACHROME MS TYPE 2448
EKTACHROME INFRARED TYPE 8443
WAVELENGTH RANGE
.5 TO .7 μm
.6 TO .9 μm
.4 TO .7 μm (3 layers)
5 TO .9 μm (3 layers)
FILTRATION USED
MINUS BLUE WRATTEN NO. 12
MINUS BLUE and GREEN WRATTEN NO. 25A MINUS B.G.R. WRATTEN NO. 89B
HAZE FILTER (HF-3) ANTIVIGNETTING FILTER
WRATTEN NO. 12 EMULSION FILTER (EF SERIES) COLOR COMPENSATING FILTER (CC SERIES)

FIGURE 2. SUMMARY OF AERIAL PHOTOGRAPHIC FILMS. THE FILM TYPES GIVEN AS EXAMPLES WERE USED FOR THIS RESEARCH.

The remote sensing systems that produce imagery do not record three dimensional form but they image reflectance and emittance. The reflectance may be due to solar energy as in the visible (0.40-0.72 μm), ultraviolet (0.32-0.40 μm) or near-infrared regions (0.72-2.50 μm) of the electromagnetic spectrum. The reflectance may be due to induced mechanical energy as in SLAR (1 centimeter to 1 meter) or thermal emission or radiation as in the far-infrared portion of the spectrum (4.0 to 14 μm).

It is beyond the scope of this report to present the concepts and techniques of airphoto interpretation and remote sensing as these are in the literature (5, 7). It is important to emphasize that remote sensing in the broadest sense includes airphoto interpretation. Remote sensing supplements airphoto interpretation by providing additional information on the environment and the reaction of materials and surfaces to the environment.

The film types used in aerial photography for highway location studies and for investigation of engineering soils and soil conditions are illustrated in Plate 1. The types of film include (left-side, Plate 1) black and white negative film, black and white infrared negative film and color negative film (12). With each film type an appropriate filter is used for specific haze conditions. Each filter absorbs certain wave lengths of light, thus, reducing the range of wave lengths recorded on the film (13). These negative films are produced normally as positive paper prints for evaluation and interpretation. The color negative film has a decided advantage in that both black and white prints as well as color prints may be produced.

B & W

C-I

B-I

C-P

C-N

C-P/C-N

Plate 1. Comparison of various film types (May 1966).

Purdue University provided funds for the printing of this color plate.

Black and white or black and white infrared prints can be prepared commercially in quantity for about $1.50 to $2.00 per print. Color prints from a negative for which a neutral anti-vignetting filter has been used (used normally in all aerial photography) can be prepared in quantity for about $3.00 to $6.00 per print fully color corrected and about $2.50 to $3.50 per print uncorrected for color balance. Fully color corrected prints are preferred and are recommended. All prices are based on continuous roll films without splices. Special set-up charges are made for prints made from individual negatives.

Color negative film can be processed to a color positive transparency (lower illustrations, Plate 1) or a color reversal film can be used to produce a color positive transparency (right middle, Plate 1) (13). Three emulsions are used on these two color films that are sensitive to blue, green and red wave lengths. The spectral range of this film is, of course, in the visible from 0.40 to 0.72 μm. Appropriate haze filters and color balance filters as well as anti-vignetting filters are used according to film manufacturers recommendations (2, 3).

Color prints made from color positive transparencies requires the preparation of a negative in a two-step operation. The cost of an internegative varies commercially from $15.00 to $35.00 and the color prints made therefrom are $3.00 to $6.00 as mentioned previously.

In this research, it was observed that the color transparencies from color reversal film exhibited sharper definition than color paper prints from color negative film. Color transparencies of course, have the disadvantage that they must be viewed stereoscopically on a special light table. They can be used in optical viewing systems in universal photogrammetric plotters or with alternator systems in double projection plotters for mapping purposes.

Color infrared positive film (upper right, Plate 1) is a special film that contains three emulsions sensitive to green, red and near-infrared wave lengths (4). A yellow filter to absorb the blue radiation is always used as is the anti-vignetting filter. The film is sensitive upon proper filtration between 0.50 to 0.90 micrometers. When processed the green-sensitive layer is developed to a yellow positive image, the red-sensitive layer is developed to a magenta (purplish-red) positive image and the infrared-sensitive layer is developed as a cyan (blue) positive image (4). This film provides a perspective view of the earth in false color. The film with proper filtration has excellent haze penetration capabilities; therefore, images in urban areas and humid environments are much sharper than with some of the other film types.

For comparison purposes, a 250-foot roll of 9½-inch wide black and white panchromatic film will cost (1970) about $85.00, black and white infrared film about $160.00, color negative about $300.00, color reversal about $500.00 and color-infrared about $500.00. Film processing by commercial firms will cost about $75.00 for black and white and black and white infrared negative film, $200.00 for color negative film and about $300.00 for the color reversal and color-infrared films.

The advantages and disadvantages for each film type for the preparation of large scale engineering soils maps as master soil plans as determined in this research project are discussed in the following sections.

Black and White Aerial Photography

Black and white aerial photographs either as stereoscopic aerial photographs or as perspective terrain views have been used for over 40 years to determine the relative location and extent of adverse terrain and soils (5, 7). The earliest application for engineering studies relates to determining the location and extent of organic terrain in the north central part of the United States for proposed highways. These applications developed in the late 1920's.

In 1940, the deductive reasoning technique of pattern analysis for interpretation of land forms, parent materials and engineering soils was developed at Purdue University (5, 7). This technique depended upon the availability of aerial photographs flown for governmental agencies at a scale ratio of 1/15,000 to 1/25,000. The most prominent scale ratio used is 1/20,000. These scale ratios are excellent for planning highway corridors and for preparing small scale engineering soils maps of regions of interest such as a county. These scale ratios are too small to serve as master soil plans for highway design and construction.

The investigations in this research indicate that large scale black and white aerial photographs annotated with soil borders can serve as a master soil plan. Black and white aerial photographs obtained at a scale ratio of 1/6000 (500 feet per inch) and enlarged to 1/2400 (200 feet per inch) or 1/1200 (100 feet per inch) are excellent in areas of low relief (less than 300 feet) for portraying the areal distribution of engineering soil groups along a proposed highway. The user of the soil map must recognize that the perspective view of the

aerial photographs contains relief displacements and other distortions that cause the mappable unit to be only a simulation of the exact soil area. To limit the distortions, a high altitude can be used with only the central portion used for a map base or a longer focal length lens can be used to minimize perspective distortions at a given scale. Orthogonal projections in true scale can be prepared by photogrammetric techniques either in the form of line maps showing areas of various soil types or as orthophoto maps annotated with soil borders. Either of these two techniques must be used in areas of high relief. The orthophoto map will probably develop as the map base in most terrain types and will be annotated with mappable units of soils and rocks.

Large scale black and white aerial photographs are excellent for detailed mapping of soil boundaries. They are very limited in the most important aspects of the regional patterns of topography and drainage. The field-of-view is limited and regional patterns cannot be detected. Best results are achieved using the small scale (1/20,000) photographs to supplement the large scale (1/6,000) aerial photography.

The black and white aerial photograph is not as complete a source on distribution of engineering soil groups and soil conditions as is color aerial photography. The black and white aerial photograph at large scale obtained in the early spring when most fields are prepared and only limited foliage has developed is excellent for mapping land forms, parent materials, coarse-textured and fine-textured soil groups, most organic soil groups, and most surface drainage forms (9, 11). The qualitative evaluation of internal and external drainage conditions of soil profiles generally can be inferred. The qualitative effect on soil development of vegetation can be determined by analysis of gray tone as uniform tones imply grass cover and mottled tones forest cover.

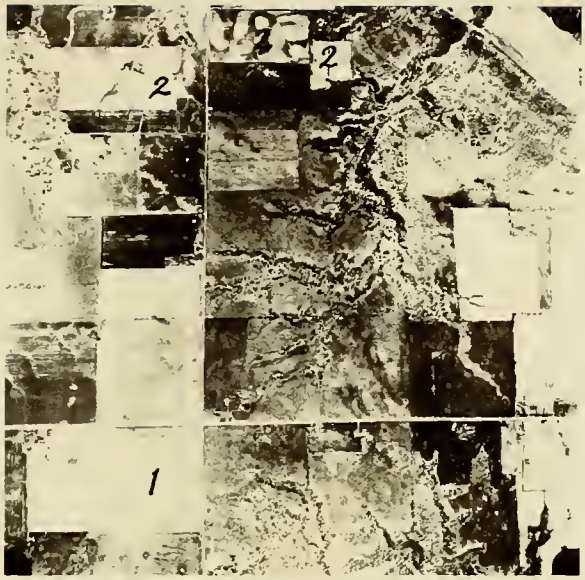
A major problem associated with the interpretation of black and white aerial photographs is the evaluation and significance of changes in gray tones (see points 3, 4 & 5 Plate 1). Are the gray tonal changes caused by soil color, soil moisture, soil composition, soil drainage, man-made practices or vegetation? It is not always possible to resolve these questions using black and white aerial photography alone even with three dimensional analysis (see points 4 and 5, Plate 1). Color photography can be used to eliminate a large part but not all of the ambiguity. Field control prior to and at the time of flight may explain most of the factors that cause gray tone changes but some are not even explainable. Rib (9) and Tanguay (11) did find that most of the significant changes in gray tones were related to a soil moisture condition, soil color, surface roughness, vegetation, or to aspects of the sun.

Highly organic soils are generally portrayed on black and white aerial photographs in dark gray to black tones (see point 7, Plate 1). Moist and wet conditions of soil surfaces or within soil profiles are indicated by medium gray to dark gray tones confined within topographically low areas. Coarse-textured soils exhibit light gray to white tones with small dark gray specks if a fine-textured surface soil has developed by processes of soil formation. Sands with low water tables are very light gray to white. Silts are medium gray except at major topographic changes where they are very light gray. Clays are medium to dark gray. Silty-clays are mottled light and dark gray with silt content increasing as the light mottles increase while the clay content increases as the dark mottles increase. Dark gray tones imply poorly drained soil conditions.

Black and white aerial photographs do not show textures of soils at the surface of the ground. The texture of the soil is inferred from all the pattern elements. The element of gray tone is important only if it is considered in conjunction with all other elements. The tones of gray on panchromatic aerial photographs may have significance if contrasts occur within or between land form types (5, 7).

A definite limiting factor in the analysis of black and white aerial photographs is the presence of and areal distribution of vegetation. Green vegetation produces dark gray tones with broad leaf species producing slightly lighter gray tones than coniferous species. The latter, of course, has smaller surface areas for reflection of light and greater shadow area between leaf surfaces. Vegetation may completely or partially mask the soil surfaces. The soils cannot then be separated except by convergence of evidence for which vegetation may be important (7).

Black and white aerial photographs are cheaper to obtain and process; therefore, they will probably serve for a long time as the primary source for mapping of terrain and general engineering soil types. Training of personnel to use airphoto interpretation properly is important. It is important also to recognize the limitations both of the technique and the medium. The medium is significantly affected by time factors as shown in Figure 3. The time factor is influenced partly by the growth of vegetation particularly as the time interval becomes longer. It is also controlled by surface soil moisture conditions caused by macro and micro climatic factors as shown at 1 in Figure 3. Rainfall has a significant effect upon gray scale values. Aeration of soils due to topographic position also changes gray tones as shown at



B & W (MAY 2, 1966)

B & W/C-N (MAY 3, 1966)

FIGURE 3. VARIATIONS DUE TO TIME FACTOR.

point 2 in Figure 3. The maximum amount of information on engineering soil groups and soil conditions is obtained from black and white photography obtained in the early spring when air temperatures are warm and moisture changes are significant.

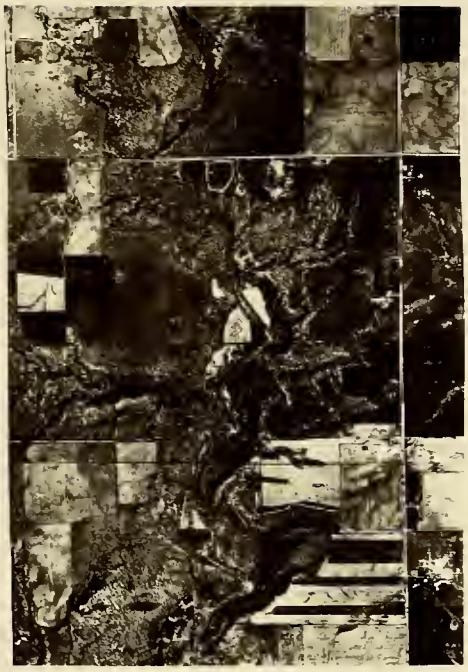
Black and White Infrared Aerial Photography

Black and white infrared aerial photography, filtered to record the 0.6 to 0.9 or the 0.7 to 0.9 micrometer wave lengths compares with standard black and white aerial photography in its interpretability and limitations of use (9, 11, 13). All elements of form are evaluated in the same manner. Examples of the two films are shown for comparison in Figure 4.

The water surfaces of streams and lakes are readily differentiated because of tonal contrasts in the near infrared region as shown in Figure 4a. Water absorbs incoming energy and is black while land and vegetation reflect to various degree and are shades of gray. Soils of different moisture content in recently plowed fields are more readily identified on this film type than on black and white. Contrasts in vegetation are more obvious because of the different gray tones produced by leaves in the reflective infrared in contrast to their background.

The overall advantage of black and white infrared aerial photography is the determination of the relative influence of moisture and vegetation on tones. No quantitative information was obtained from this film type (9, 11). The slight additional qualitative information obtained does not, in the opinion of the author, justify obtaining black and white infrared aerial photography for large scale engineering soils studies.

A. BLACK AND WHITE INFRARED (.6 TO .9 μm) PRINT (6/66)



B. BLACK AND WHITE (.5 TO .7 μm) PRINT (6/66)

FIGURE 4. COMPARISON OF DRAINAGE PATTERNS EVIDENT ON PHOTOGRAPHY.

Black and white infrared aerial photographic film has much better capability to record images in a humid atmosphere because it records near infrared radiation and is filtered to reject blue light reflectance. Exposure problems occur in some instances because the aerial camera may not be properly calibrated or set to accommodate the wave lengths in the 0.7 to 0.9 micrometer region. Filters must be used with the black and white infrared films.

Color Aerial Photography

Color aerial photography may be of the reversal type or the negative type (13). Color aerial photography obtained through anti-vignetting filters and the correct haze filter is the most useful medium for large scale mapping of engineering soils (9, 11). Color has no advantage over other film types in the identification of elements of form. Color has the greatest value in differentiating or evaluating objects and conditions where the intrinsic color is of importance. Many soils have unique colors such as unoxidized soils are blue-gray and oxidized soils are buff, brown or red.

Color transparencies from reversal film are generally better than color prints from negative film for purposes of interpretation. Transmitted light is always purer than reflected light. Color prints, of course, must be used to prepare the large scale mosaic which may serve as the base map for soil mapping purposes. These mosaics should be made from fully corrected and balanced color prints. Fully color balanced prints in mosaic form will have imperfect color rendition over a large area or a long flight line. This factor of change in color between photographs and even on individual photographs is due in large

part to the relative position of the sun and the center of the perspective view. Color photography obtained during this research showed variations in absolute color in each quadrant of each perspective view. It was observed that the black and white and the black and white infrared as well as color-infrared showed these same variations but not as strikingly. These variations will probably occur at all times for all film types and will not preclude their use for mapping purposes.

The advantage of the natural color of soils and soil conditions on the photography make it possible to determine the relative influence of intrinsic soil color, soil moisture, vegetation and cultural practices as illustrated at the several points shown on Plate 1. It must be recognized that even the best color film does not reproduce the absolute color of all objects and surfaces within the field of view. Color is a very complex subject and many physiological and psychological factors enter into its evaluation. Different colors evoke different emotions and degrees of activity. Emotion and activity rises with increase in the wave length. Irrespective of all the problems, color aerial photography is the most complete information storage system on terrain that has been devised by man. The problem of the airphoto interpretation specialist is to extract the useful or pertinent information and put it into usable form. The color aerial photographs, therefore, must be annotated with boundaries to show aerial distribution of statistically unique soil conditions.

Color reversal film has a higher contrast and interpretability than color negative film. Reversal films produce a sharper image than color negative film of the same speed and reduce the loss in image sharpness associated with printing. The exposure latitude for reversal film generally is more critical than for negative film. If the exposure

is not in the correct range ($\pm \frac{1}{2}$ f-stop) it is more difficult to obtain proper color balance with the reversal film (2, 3). The exposure of color films should be selected in order that reflectance from the terrain may be recorded on the linear portion of the characteristic curves of the appropriate sensitive layer. This will give the maximum amplification of variations in terrain exposures and result in the greatest color contrasts. The color balance in the film manufacturing may be readily changed by the use of appropriate color compensating filters as recommended (2, 3).

Bare soils tend to have a maximum reflectance variation in the 0.6 to 0.7 micrometer portion of the spectrum. This range is included in the spectral sensitivity of color, color-infrared, and panchromatic films (13). In this region of the spectrum and considering the complex nature of the reflecting surfaces of the natural and cultural terrain, color positives either as transparencies or prints offer greater ease in identification of soil groups and rock exposures and consequently field checking may be reduced.

Tanguay (11) and Rib (9) emphasized that boundaries between various soil types or between rock exposures and soil could be more easily and accurately delineated with color film. Color film will give the optimum image of underwater terrain but it is dependent upon atmospheric conditions, the transparency of water and the filter used. Maximum penetration of solar energy into water occurs in the 0.44 to 0.49 micrometer region which is recorded on color aerial photography.

Color is an asset in mapping engineering soil groups and soil conditions. Intrinsic color assists in identifying organic soils and mucks and in separating them from moist or vegetated areas. This is

frequently difficult on black and white aerial photographs. The reddish residual soil associated with limestone was readily differentiated from the brown soils developed on shale, the buff colored soils of loess or the gray soils of the alluvium on the mapping project conducted by Tanguay using good quality color aerial photographs (11).

Rib observed that more detailed information on soils could be obtained by using smaller scale color aerial photographs under magnification than other films under magnification or at a larger scale (9). For similar detail of mapping, smaller scale color aerial photography can be used to give comparable data to larger scale black and white photography. This fact may compensate for the difference in cost. The soil boundaries mapped using color aerial photographs can be located with much greater ease and the interpretation is more accurate as to general soil groups.

Rib (9) and Tanguay (11) observed that with natural color it was easier and faster to make positive identification of objects and terrain conditions. Similar gray tones on black and white prints could be differentiated on color positives and generally the reason for the color change, such as plowing, could be inferred. The recorded color of earch materials is largely controlled by the mineral composition of the materials, surface roughness, surface moisture, viewing angle and vegetation. If specific effects of these items can be evaluated then it may be possible to infer composition of the earth materials.

Color aerial photography, as is all photography, is limited in application where dense tree growth obscures the ground surface for the interpretation of soils. If 30 to 60 percent of the actual ground surface is visible, then by interpretation of elements of form as well

as colors it is possible to prepare annotated aerial photographs as master soil plans for proposed highways.

Cost savings can be achieved by using color-negative film and producing alternate prints in natural color with intervening prints in black and white. The matching of color and black and white in stereoscopic registration may assist in mapping soils.

Color-Infrared Aerial Photography

Color-infrared aerial photography has the advantage over color aerial photography in emphasizing the location and extent of living vegetation. As mentioned previously, living vegetation is portrayed on color-infrared aerial photographs in red hues. During the summer period the reds may completely saturate the aerial photographs and the photography may be of only limited value in engineering soils mapping. Color-infrared aerial photographs have very limited value in evaluating fall and winter scenes.

Another advantage of this film type is that it shows in the blue-green wave lengths the relative moisture conditions of the soils as influenced by topography, internal drainage and aeration. Darker hues and values of blue-green indicate high moisture conditions within the terrain situation. Tanguay (11) and Rib (9) both concluded that color-infrared transparencies provided more information than the other film types relative to soil drainage conditions, wet zones or moist zones with thin development of vegetation. No quantitative information on these conditions was obtained.

Muck and highly organic soils were not always as easily detected and identified in comparison to color film positives or color prints. This problem was encountered where the red hues of the vegetation

masked the conditions. It was not possible to quantify the soil moisture conditions or the amount of organic matter using color-infrared photography nor any other film or sensor system. Field measurements are always necessary for control, but a few good field measurements may be projected on a statistical basis over a large area using aerial photography.

Highly plastic red clays in the limestone plains studies were portrayed on color-infrared aerial photography in different hues and values of green depending upon intrinsic color and surface soil moisture. These clays on this film and filter system would be expected to show in characteristic hues of greenish-yellow to yellow for the light brown-red to deep red clays respectively. The red clay soil areas were easier to identify on the color film than on the color-infrared film primarily because of lack of familiarity with the color shift produced in the latter film system. Training to recognize these shifts in color is relatively difficult because so little information is available on the reflection of surfaces in the restrictive wave lengths employed particularly in the 0.7 to 0.9 micrometer wave lengths.

Soil contrasts due to composition, texture, surface roughness, etc. are detectable on color-infrared positive transparencies just as they are on color positive transparencies. An item or condition identified on one is normally identified on the other if the color shift is accounted for.

The major advantage observed in almost all instances of use of color-infrared positive transparencies is the sharpness of detail produced through a column of the atmosphere. Color-infrared photography, therefore, is recommended whenever adverse haze or light smoke

conditions are expected prior to or during photography. The engineer using this photography must have a good background in evaluating the change in natural colors as recorded by this film type. For engineering soil mapping purposes at large scale the use of this film type is limited. For reconnaissance mapping at small scale from high altitudes, the film in three dimensional analysis will provide an order of magnitude sharper detail on elements of form than other film types.

Infrared Imagery

Special sensors of the Forest Service (HRB-Singer Reconofax XI-4.5-5.5 μm) and the University of Michigan (multispectral M5 Scanner 0.8-1.0 μm, 1.5-1.8 μm, 2.0-2.6 μm, 3.0-4.1 μm, 4.5-5.5 μm, 8.0-13.5 μm) were used to record the infrared energy eminating from the ground. The continuous line scanner detector output of these sensors is amplified and converted to light signals recorded on film. The reflective infrared or the thermal infrared wave lengths may be recorded on film. Positive film shows high infrared energy as light gray tones and low infrared energy as dark gray tones. The light signals are registered over a 16-step (linear voltage) gray scale. The infrared imagery is highly distorted but a usable record in clear weather of either daytime or nighttime emittance is obtained. In daytime the sensor is recording solar reflectance below 3.5 micrometer and emitted radiation above 3.5 micrometer. At night the effects should be the same as emittance is recorded. A discussion of parameters affecting infrared imagery is contained in the report by Rib (9, p. 105).

The analysis of infrared imagery obtained during this study indicated that water surfaces, moist soil surfaces, dry soil surfaces, vegetative surfaces and man-made surfaces could be delineated on daytime or nighttime imagery using gray scale values. In general, reversals occurred between daytime and nighttime imagery i.e. dry fields were very light gray in the daytime and medium dark gray at night, water surfaces were black in the daytime and white at night, and low growing vegetation in moist soils were medium dark gray on both day and night imagery. These features are illustrated in Figure 5. Dew has an effect on nighttime imagery, therefore, time of flying and surface condition is critical.

The attempt to correlate ground temperatures or radiometric temperatures obtained in the field at time of flight with relative temperatures represented by calibrated gray scale values on the imagery proved valueless (11, p. 230). No absolute temperature values were obtained from the infrared imagery that could be correlated with specific soil temperature or soil moisture that is of value in mapping engineering soil materials. Probable moist or wet surfaces could be detected for correlation with black and white, color or color-infrared aerial photography.

No particular advantage could be assigned to the use of infrared imagery alone in studies of terrain. More problems of identification of causes of gray tone changes recorded on the imagery occurred than could be explained. It is believed that infrared imagery would have its greatest value in detecting relative temperature changes on essentially uniform surfaces such as bodies of water. Complex terrains consisting of different soil moisture conditions, land-use conditions, vegetative conditions, and water surfaces exhibit dynamic range beyond the capabilities of the equipment available. Also, the user has available

DAYTIME – 1112 HRS. – JUNE 2

NIGHTTIME – 2056 HRS. – JUNE 1

WAVELENGTHS: 8 – 13.5 MICROMETERS

FIGURE 5. INFRARED LINE SCAN IMAGERY.

only very limited knowledge of the thermal characteristics of the natural environment. At no time was there any indication of underground (area of known caves) thermal anomalies. The indications are that the information on the imagery represented temperature data relative to a monolayer at the air-ground interface.

The cold, warm and hot surface temperatures indicated by gray steps could be of some value as a supplement to evaluation of black and white, color and color-infrared aerial photography to determine soil surface conditions. Contrasts were observed in comparing the photographic infrared (0.8-1.0 μm), middle infrared (3.0-4.1 μm) and the far infrared (8-13.5 μm). The specific soil condition that can be evaluated where there is no vegetation or land use practice is the relative affect of soil moisture (9, 11). Frequent coverage would be required to obtain information on the multitude of diurnal effects. It is doubtful if the benefits can justify the cost of infrared surveys for engineering soil studies produced at large scale where only an infrared line scanning system is employed.

If infrared imagery is used it is recommended that both daytime and nighttime imagery be obtained within a 24-hour period (9, 11). This restricts the spectral band width to the 3.0-13.5 micrometers. Also, field termperature measurements of large, flat, uniform surfaces should be obtained. Contact sensors of temperature as well as radiometric temperature sensors should be used in the field environment. The surfaces should represent the field temperature extremes such as a lake surface and the surface of a flat roof or road. Considerable research needs to be performed to develop correlations of soil conditions, heat conductivity, infrared emissions and imagery evaluation.

Multichannel Imagery

Multichannel imagery was obtained using the M-5 Scanner developed at the Willow Run Laboratories at the University of Michigan. The M-5 Scanner records in 18 channels; one channel records the ultraviolet (0.32 to 0.38 μm), twelve channels the visible (0.40-0.44, 0.44-0.46, 0.46-0.48, 0.48-0.50, 0.50-0.52, 0.52-0.55, 0.55-0.58, 0.58-0.62, 0.62-0.66, 0.66-0.72, 0.74-0.80, 0.80-1.00 μm) and five channels the infrared (1.5-1.8, 2.0-2.6, 3.0-4.1, 4.5-5.5, 8.0-13.5 μm). Examples of 17 channels are shown in Figure 6. The 4.5-5.5 μm spectral band is similar to the 8.0-13.5 μm band.

The evaluation of the imagery in the infrared regions was discussed in a previous section. Notice the contrasts of the thermal region and reflective region above 0.72 micrometers shown in Figure 6. The infrared imagery was used also for visual comparison with the imagery in the visible and ultraviolet regions. The multichannel imagery was evaluated by making visual comparisons and, also, by analog to digital conversion using a computer for a statistical analysis of reflectance recorded by the sensor system (14).

The multichannel line scanner imagery is distorted both along and perpendicular to the line of flight. The line scan is an S-shaped form on the imagery. The system is formatted to present the 37 degree thermal ground scan on film at the same scale as the 80 degree scan of the reflective channels as shown in Figure 7. The terrain to film scale factor is the flight altitude. For the southern test area, two scale factors were used - 1600 feet per inch and 3200 feet per inch. These scales are too small to develop visually or automatically information for large scale mapping of engineering soil groups.

MULTISPECTRAL SCANNER IMAGERY

IN 17 WAVELENGTH BANDS, INCLUDING

·Ultraviolet (.32-.38) ·Visible (.40-.72) ·Reflective Infrared (.72-4.1) ·Thermal Infrared (8-14)

FIGURE 6.

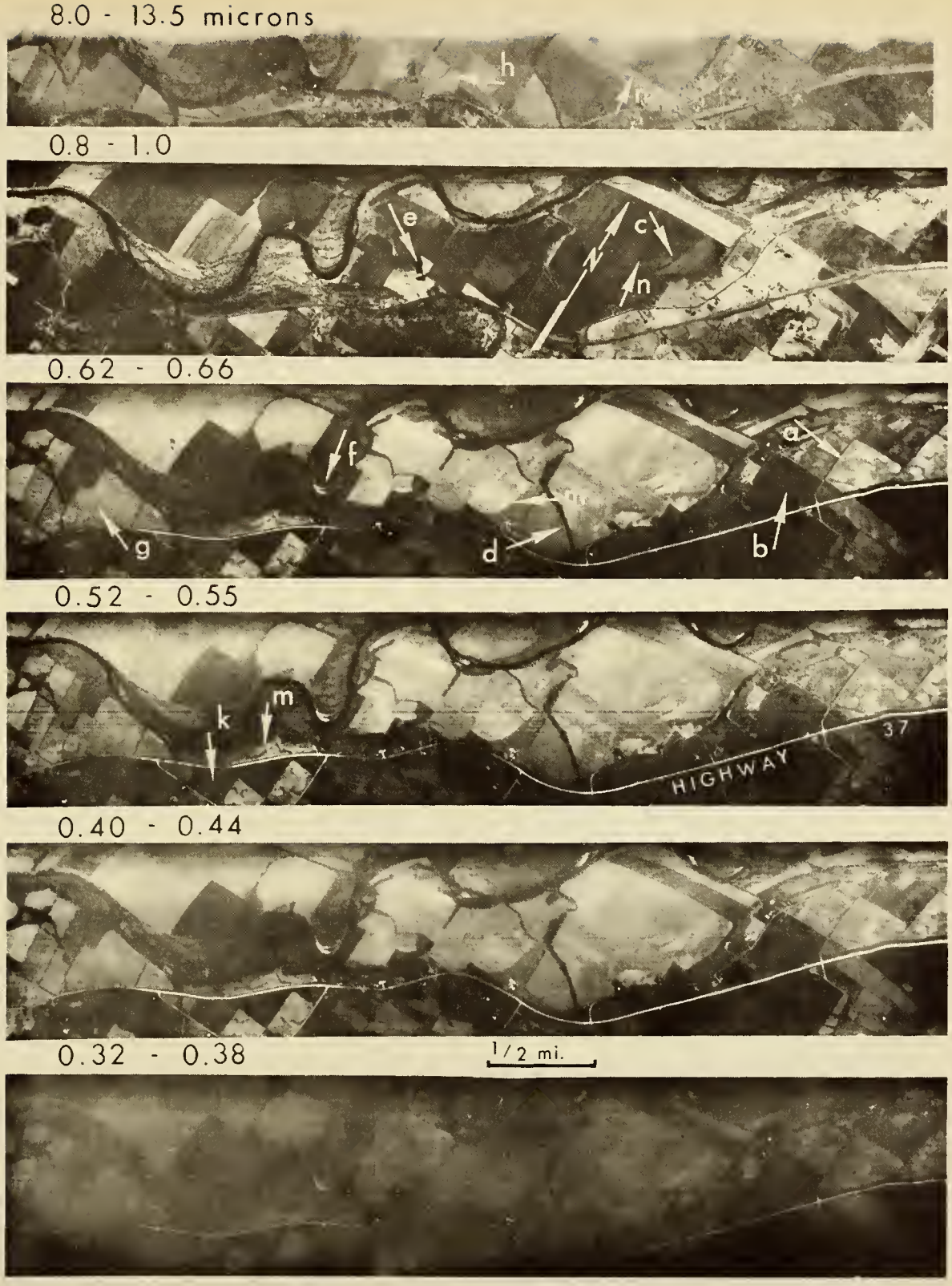


FIGURE 7. EXAMPLE OF MULTI SPECTRAL IMAGERY (AREA 4)

The visual comparison of all the multichannel imagery over a large region is almost an impossible task. Eighteen channels with each channel having a 16-step gray scale presents 16^{18} possibilities. Rib reported that he could evaluate up to seven different bands (9). Tanguay reported that he could examine six bands but four bands were better (11). In both cases, the evaluation was restricted to very small segments of the imagery in areas essentially devoid of vegetation as illustrated in Figure 7.

The visual evaluation of multichannel imagery indicates that soil color contrasts were best detected in the red (0.62-0.66 μm) and green (0.52-0.55 μm) portions of the spectrum as illustrated at a, b, f and m on Figure 7. Water bodies showed best in the far infrared (8.0-13.5 μm) and reflective infrared (0.8-1.0 μm) portions of the spectrum. No information was obtained on subsurface features. All items identifiable are "first surface" reflectance or emittance. Vegetation of any type and height has a greater effect than soil conditions on reflectance and emittance in the several restrictive wave lengths. The multichannel imagery has the advantage that the multispectral information is collected at a similar scale, resolution and format.

Rib and Tanguay performed densitometric measurements of selected portions of the multichannel imagery to attempt to develop spectral response signatures of soil surfaces (9, p. 259; 11, p. 217). The densitometric measurements were "normalized" relative to a standard gray scale. The densitometric approach is slow and cumbersome. The "signatures" of soil and rock materials obtained did show uniqueness as shown in Figure 8. This confirmed what had been known from a visual

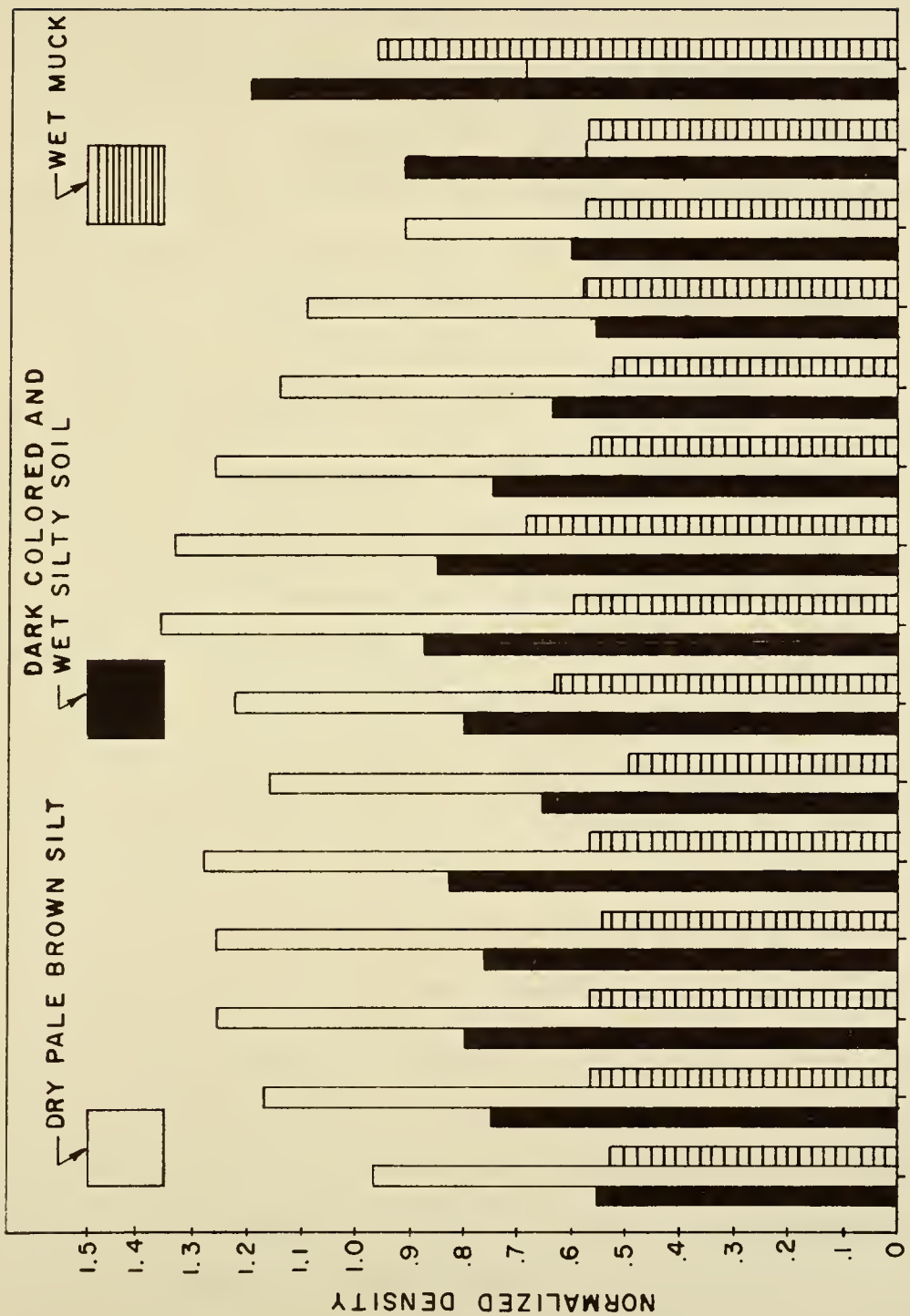


FIGURE 8. SPECTRAL RESPONSES FROM DENSITY MEASUREMENTS FOR THREE SOILS

examination of the photography and imagery. No statistical analysis was performed to determine if the densitometric measurements alone could be used to classify areas of unique engineering soil types or soil conditions. This type of analysis must be performed using a computer. It is more economical and practical to ignore the imagery and densitometric measurements and proceed directly from analog to digital conversion with a computer analysis of the data collected by the sensor. An example of this analysis is shown in Figure 9.

Figure 9 illustrates the statistical results obtained for a unique area (training sample) of sandy soil on the left and an organic silt on the right. The tables at the top give the mean, standard deviation, covariance matrix and the correlation matrix of the reflectance data. The graphs show the spectral plot in each wave length channel for the mean plus or minus one standard deviation. Differences in response in at least one channel is fundamental to using the computer to assist in classification of surfaces of reflectance as obtained by a multi-channel sensor (14). Note that there is no meaningful relationship of the response of a particular material in the different wave length bands.

The computer analysis of multichannel data is used to determine if the training samples of specific soil groups are separable on the basis of spectral plots or signatures. Figure 10 illustrates the spectral plots in the visible portion for eight different classes. The top diagram shows that sand surfaces (D) can be differentiated from three vegetative classes because of unique reflectance in the five middle wave lengths of the visible spectrum. In the reflective infrared (E) the data overlap. Individual wave lengths may be of little value in mapping soils but statistical differences in several

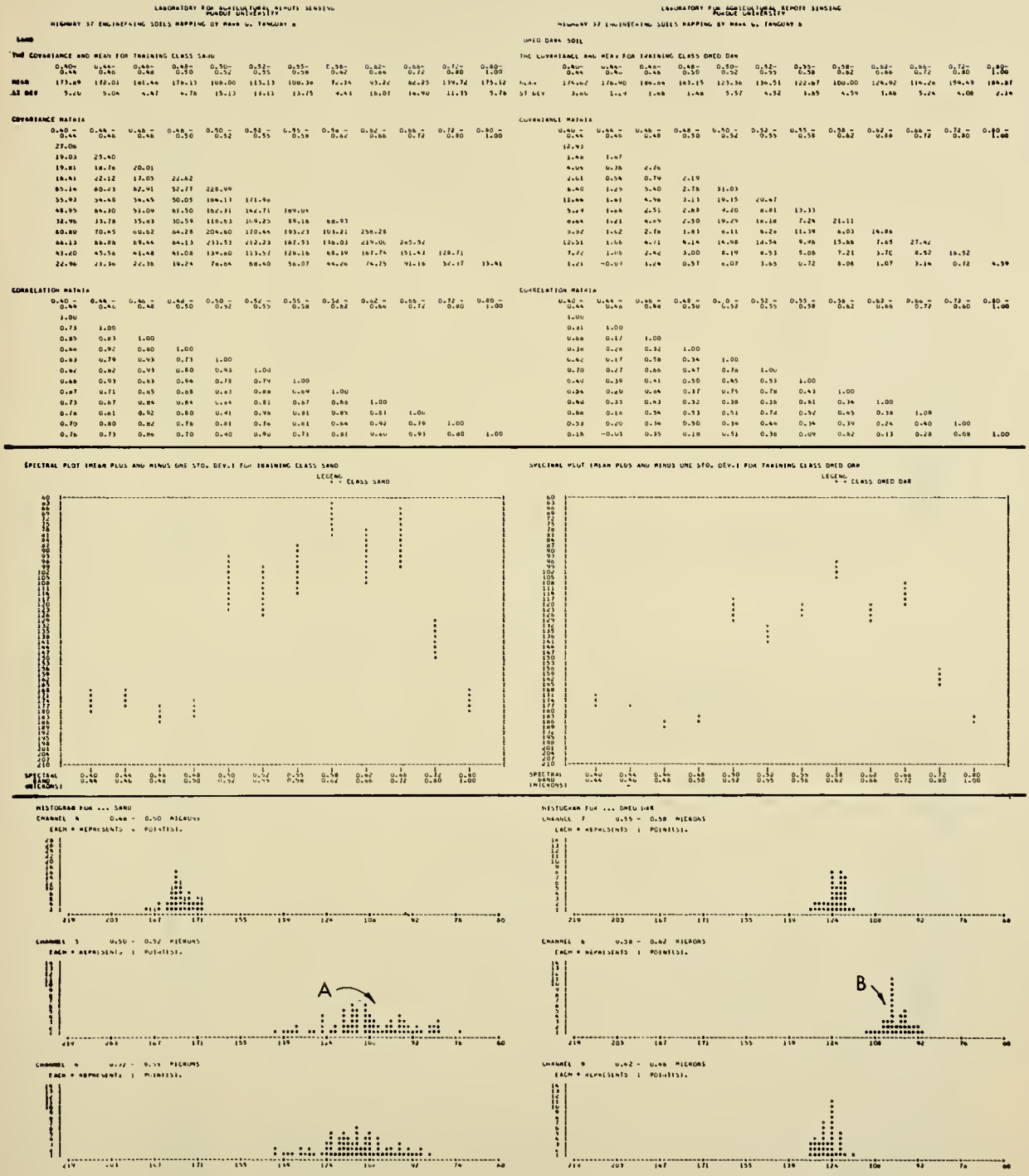


FIGURE 9. EXAMPLES OF STATISTICAL ANALYSIS OF MULTICHANNEL SENSOR DATA.

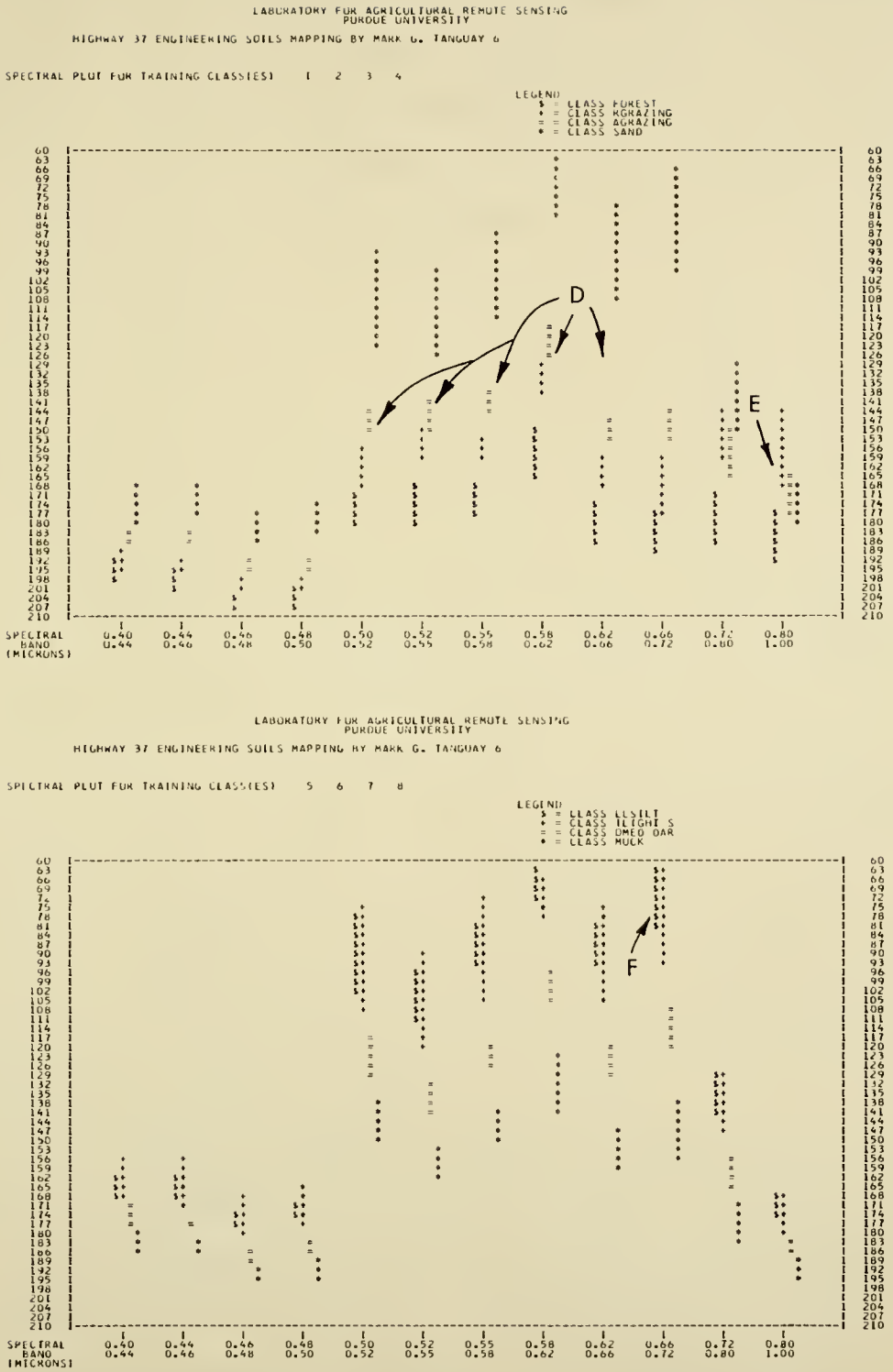

LABORATORY FOR AGRICULTURAL REMOTE SENSING
PURDUE UNIVERSITY
HIGHWAY 37 ENGINEERING SOILS MAPPING BY MARK G. TANGUAY 6
SPECTRAL PLOT FOR TRAINING CLASS(ES) 1 2 3 4
LEGEND
$ = CLASS FOREST
+ = CLASS RGRAZING
= = CLASS AGRAZING
* = CLASS SAND
D
E
SPECTRAL BAND (MICRONS)
0.40 0.44 0.46 0.48 0.50 0.52 0.55 0.58 0.62 0.66 0.72 0.80
0.44 0.46 0.48 0.50 0.52 0.55 0.58 0.62 0.66 0.72 0.80 1.00
LABORATORY FOR AGRICULTURAL REMOTE SENSING
PURDUE UNIVERSITY
HIGHWAY 37 ENGINEERING SOILS MAPPING BY MARK G. TANGUAY 6
SPECTRAL PLOT FOR TRAINING CLASS(ES) 5 6 7 8
LEGEND
$ = CLASS CLSILT
+ = CLASS CLIGHT S
= = CLASS DMED OAR
* = CLASS MUCK
F
SPECTRAL BAND (MICRONS)
0.40 0.44 0.46 0.48 0.50 0.52 0.55 0.58 0.62 0.66 0.72 0.80
0.44 0.46 0.48 0.50 0.52 0.55 0.58 0.62 0.66 0.72 0.80 1.00

FIGURE 10. SPECTRAL PLOTS FOR EIGHT CLASSES.

wave lengths may be of value. In the lower diagram, point F shows that two silty textured soils selected as training samples based on slight differences in gray value on aerial photographs exhibit very little difference in the 0.66-0.72 micrometer wave length or in other wave length bands. Based on reflectance in all wave lengths these soils could be classified in one group separable from organic silt and from muck. These diagrams also show that certain wave lengths produce a more unique differentiation than other wave lengths. Fundamentally the selection of optimum bands is based on the degree of spread between the classes of interest and the variation within the class response for all possible combinations of the different wave lengths (14).

The use of multichannel reflectance data in conjunction with computer analysis enables semi-automatic classification of reflective surfaces (14). Figure 11 illustrates the results. On the left is a black and white aerial photographic mosaic used to select training samples for computer analysis of nine different reflective surfaces. The middle diagram shows how the computer would classify all the reflectance data relative to these nine surfaces. The diagram on the right shows how the computer could be used to select specific areas of interest with "g" representing coarse-textured, well-drained soils and "h" fine textured, organic, poorly-drained soils.

Figure 12 shows the effect of topography, surface drainage and vegetation on reflectance data analyzed by computer. The photo mosaic was used to select dry soils and wet soil conditions and the computer symbol "H" was used on the printout. Good correlation exists between the wet soils classified by the computer and as shown by "a, b, d and f" on the mosaic. Notice that all vegetative surfaces were rejected from analysis; therefore, wet soils under the vegetation were not mapped (Notice left of road at point a).

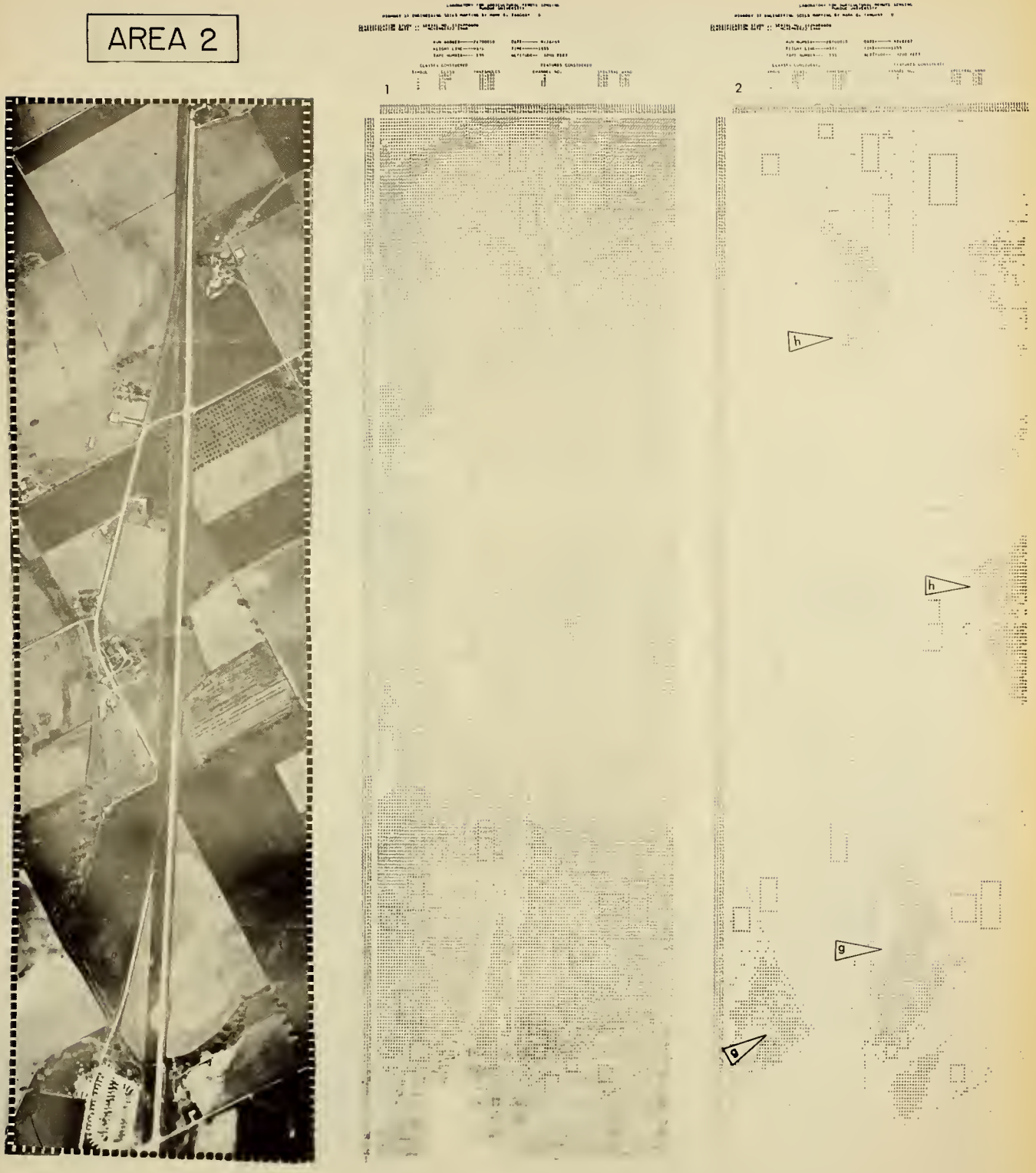
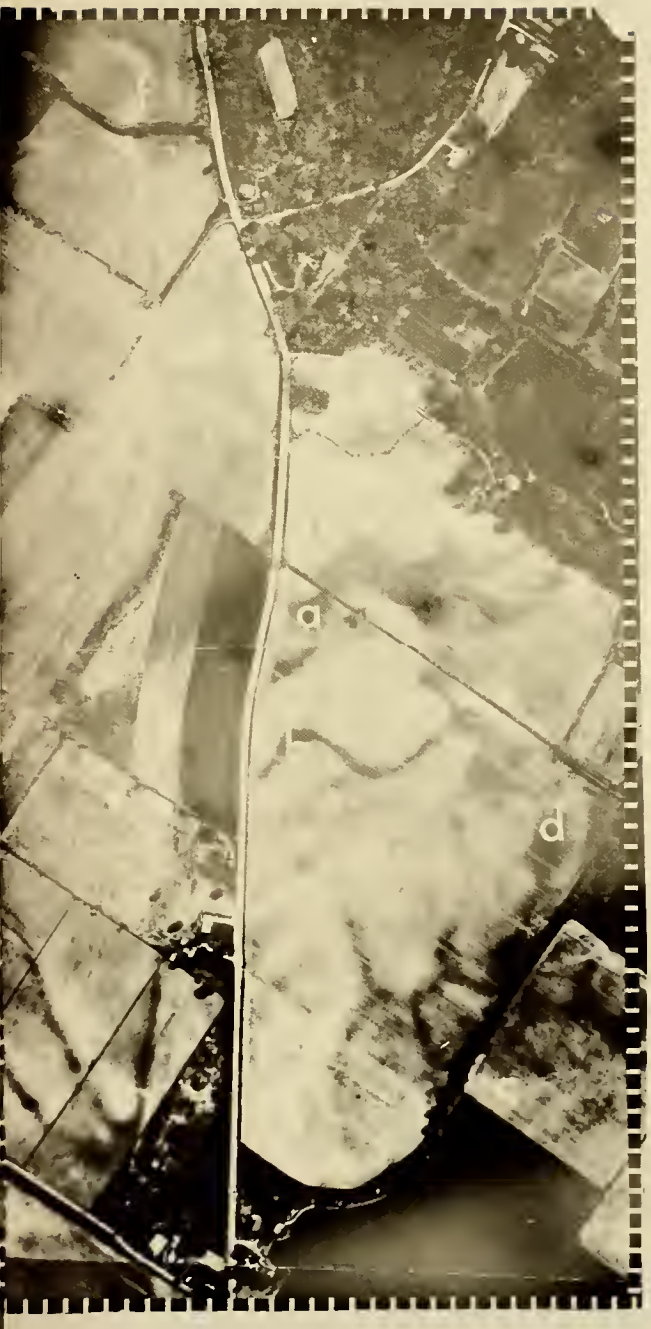


FIGURE 11. EXAMPLE OF COMPUTER CLASSIFICATION OF REFLECTANCE VALUES IN THE VISIBLE SPECTRUM.

AREA 5



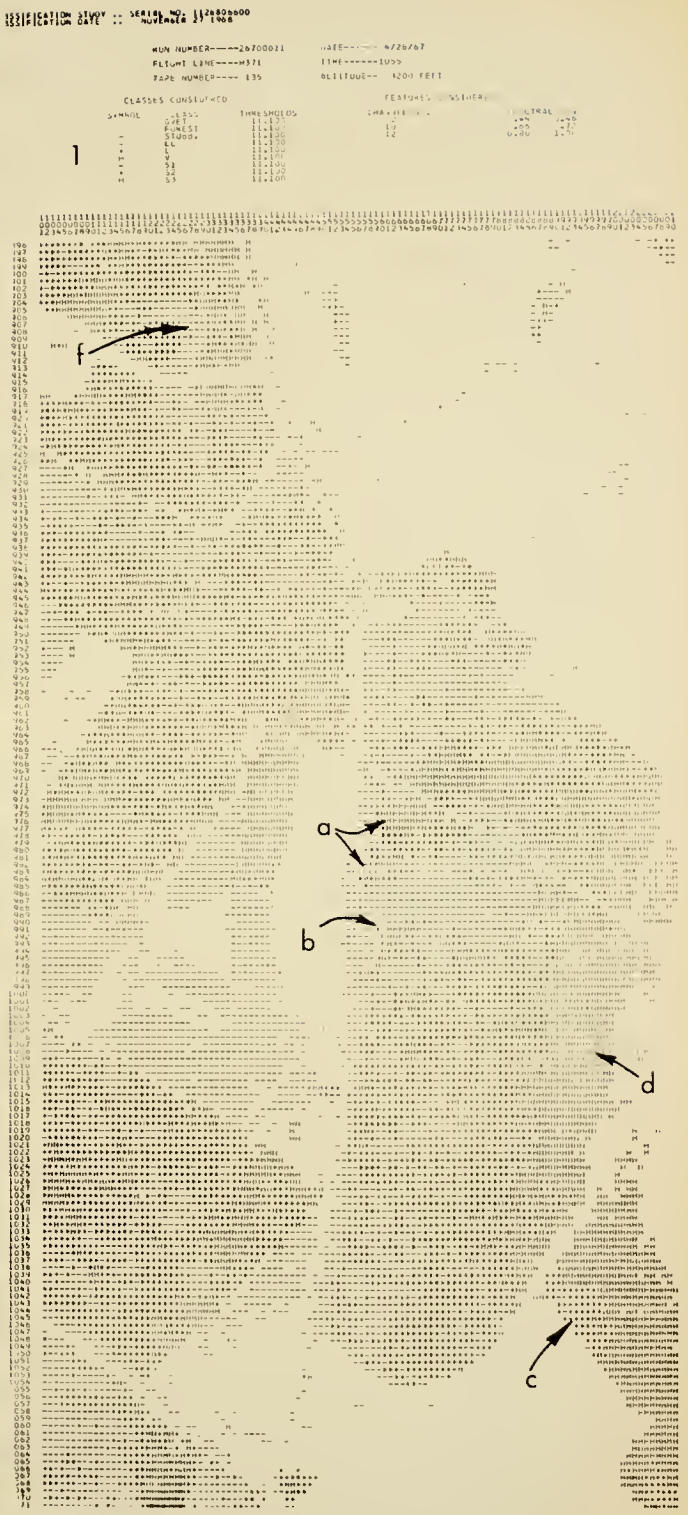


FIGURE 12. EFFECT OF TOPOGRAPHY, DRAINAGE AND VEGETATION ON REFLECTANCE DATA ANALYZED BY COMPUTER.

Figures 11 and 12 demonstrate that natural and agricultural vegetative patterns and their reflectance limit considerably the semi-automatic mapping of engineering soil groups by computer analysis of multichannel reflectance data. If all fields could be plowed at the same time and be subjected to the same exposure to solar energy then the semi-automatic system would be practical. The system in its present development has definite application to land use mapping and to studies of vegetation in humid areas such as Indiana. The maps are not true geometrical presentations of the earth surface nor are they perspective presentations with distortions similar to those on an aerial photograph. They can be correlated with and may supplement the black and white or color aerial photograph.

The investigation of multichannel reflectance data in this research program revealed no quantitative information on soil texture, soil moisture, soil depth, soil strength or other soil parameters of primary interest to the engineer. It is observed that judgement was used to select training samples on the basis of airphoto interpretation which is qualitative and objective. The computer verifies similar areas on a statistical basis. The multichannel statistical analysis complements the three dimensional and tonal study made using aerial photography in either black and white, color or color-infrared.

It is estimated that the cost of obtaining the multichannel data is about $100 to $250 per lineal mile of highway. The use of the computer in this type of application is in the research phase; therefore, a cost cannot be assigned. The information content of the multichannel analysis must yield a significant return per mile in savings in cost of construction or at least cause a change in design that increases the stability and durability of the highway design.

Side-Looking Airborne Radar Imagery

The side-looking airborne radar (SLAR) imagery obtained for this study was at K-band frequencies in the 0.83 to 2.75 centimeter wave lengths. All the imagery is only two dimensional but relative relief can be obtained by trained personnel on the basis of returns. An example of SLAR imagery of a part of Tippecanoe County is shown in Figure 13. The imagery was obtained through thick cloud cover at an extremely small scale (approximately 1/100,000). The small scale generally obtainable with existing equipment precludes the use of SLAR except for regional studies of general highway corridors and their relationship to major land form types.

General topographic class, water form, land use class and vegetative class can be identified on SLAR imagery by the active signal return recorded as light or dark tones on a photographic emulsion. A topographic slope, a railroad rail and trees oriented properly to the signal generated will show a light (white) gray tone or high return while a level surface, a water surface, a highway surface or a plowed field will show dark gray tones or no signal return as shown in Figure 13. On Figure 13, the river and flood plain are obvious as are the cities on the right side of the illustration.

The SIAR imagery at low resolution provided no unique information on engineering soil groups or engineering soil conditions of moisture, depth of development or particle size for large scale mapping of soils. General information on land form type and degree of dissection by streams or amount of vegetative cover can be obtained for small scale mapping for planning purposes. The ability to identify major land forms and land use types on SLAR imagery at small scale during adverse weather may be of value in reconnaissance studies and corridor studies in developing areas of the world.

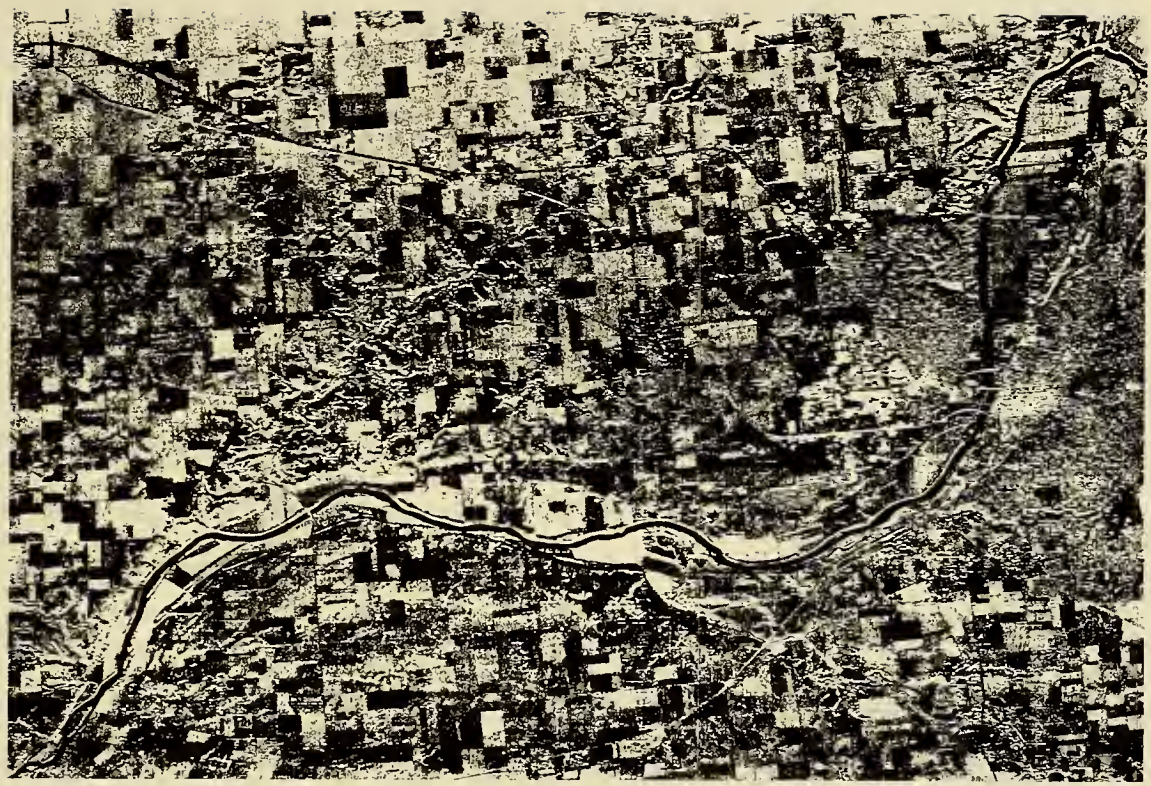


FIGURE 13. SIDE-LOOKING AIRBORNE RADAR IMAGERY, TIPPECANOE COUNTY, INDIANA.

The SLAR imagery used in this study revealed that the signal generated was reflected by the first surface of mass encountered. Small leaf surfaces and other small surfaces may not have been resolved because of system design parameters. No evidence exists that at the wave lengths used in this study was there a penetration of the soil mass and reflectance from the underlying bedrock mass. All vegetative forms may not have been resolved; thus, the energy may be reflected off of the ground surface as well as the vegetative surface.

SLAR imagery is not nor was it intended to be applicable to large scale mapping of engineering soils and soil conditions. The interpretation of the imagery is applicable to reconnaissance studies of large areas. Correlations are made between the returns recorded and the inferred land form type as revealed by two dimensional analysis of topography, drainage, vegetation and land use patterns. The evaluation of SLAR imagery is somewhat analogous to the evaluation of a semi-controlled mosaic made from the effective coverage of each aerial photograph.

ENGINEERING SOIL MAPS

Engineering soils maps for final design and construction can be prepared in various formats. The research reported indicates that annotated aerial photographs in the form of strip mosaics are the most complete information storage system available. Properly annotated they show areal distribution of engineering soils and soil conditions relative to the total environment. The optimum film type to use is natural color negative film with alternate negatives printed as fully corrected color positive prints. The intervening prints are black and white positives made from the color prints. The scale of the negative and prints for design or construction type mapping should be 200 feet per inch (1/2400). The alternate color prints should be laid down in

a strip mosaic form along the proposed centerline. The centerline stations or every second or fourth station should be appropriately flagged (Red or Orange) in the field prior to the photography. These centerline stations can then be used as reference points for correlation with soil borders portrayed on the perspective aerial photographic mosaic.

The annotated engineering soils strip map is prepared by using the alternate prints in black and white (or color) in conjunction with the color strip mosaic to analyze stereoscopically the airphoto pattern. The airphoto interpretation elements of form and elements of color (tone) are analyzed and synthesized to develop boundaries of different engineering soil types or different engineering conditions that might be significant in design and/or construction. The boundaries of soils and outcrops are placed directly on the color mosaic using a removable type pencil line.

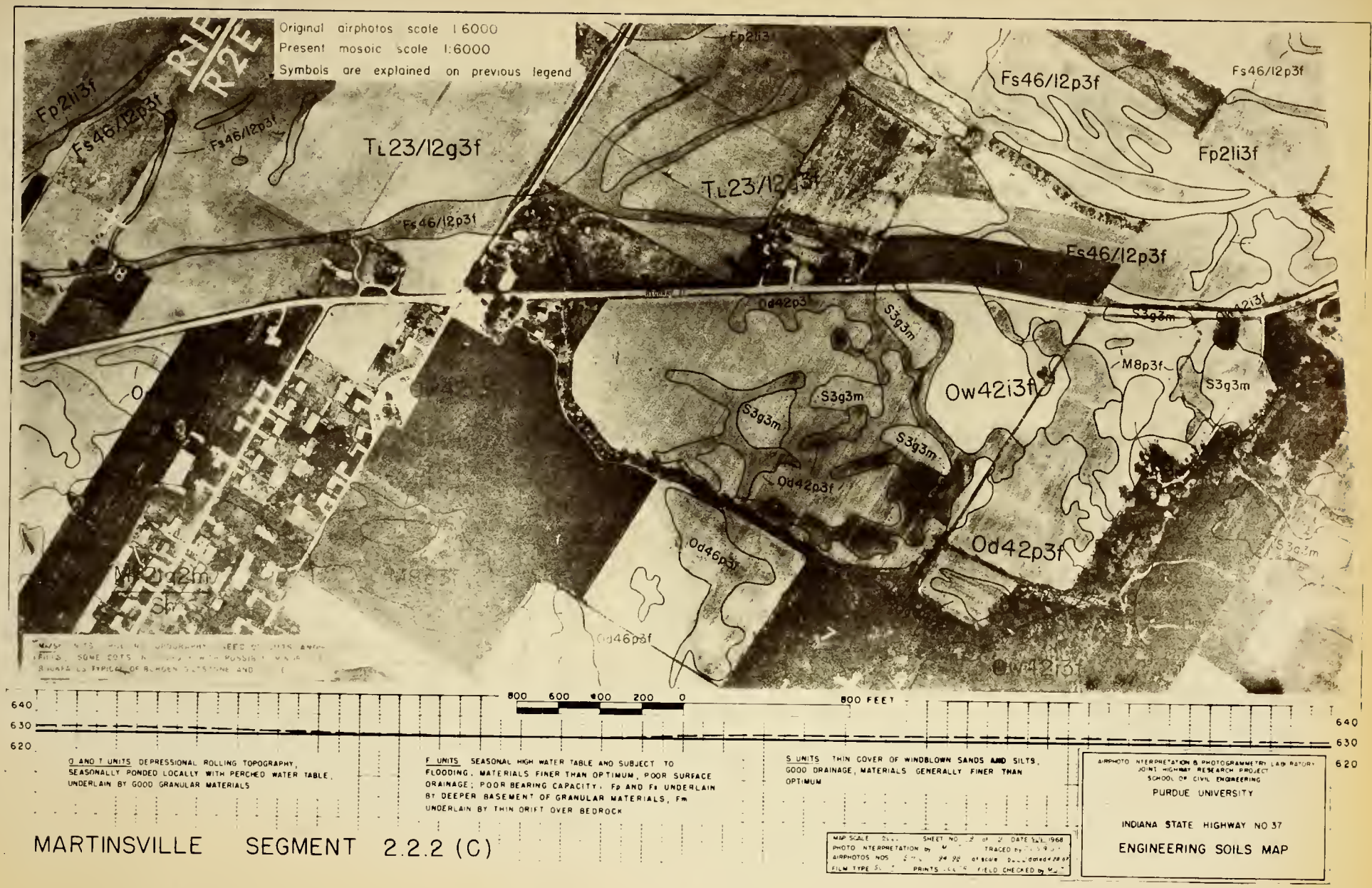
The soil areas delineated represent statistically uniform soil types, soil drainage or soil profile development or combinations that warrant field investigation. Each unique area or condition must be sampled over the route of study to determine the three dimensional extent of the soils and to collect soil samples from each horizon for laboratory testing (12). Four to ten samples per horizon per significant soil area will provide the statistical range of the design parameters (12).

After field checking and laboratory testing the three dimensional pattern is reevaluated and the final soil boundaries are delineated. The appropriate map legend is developed. The legend should show the land form type, the parent material type, and the texture of the parent material. This annotated strip mosaic and legend is then copied using

a copy camera and color negative film or it can be copied in black and white for reproduction of large numbers of strip maps. The annotated negative is then used to produce the required number of fully corrected color prints for use by the design engineers, materials engineers and construction engineers. An example in black and white reproduced from a color mosaic is shown in Figure 14. The color strip maps would have the three-dimensional features of the ground line, grade line and soil profiles shown on a separate profile sheet.

An alternative to the above would be the taking of the color aerial photographs in the scale range of 600 (1/7200) to 400 feet per inch (1/4800) depending upon topography of the site. These small scale color aerial photographs after annotation on the negative or with a mask would then be prepared as color enlargements at 200 feet per inch (1/2400) in the form of a color mosaic strip map. A higher altitude would reduce the perspective displacement, provide fewer photographs for stereoscopic analysis, be cheaper in first cost but the cost of the enlargements would be considerable. The portion to be enlarged would be the section of each negative along the centerline of the proposed facility. It is estimated that the cost would range from $0.75 to $1.50 per square inch of enlargement. A highway department may develop in-house capability to perform this work.

The color mosaic strip map annotated with soil boundaries and containing soil profiles would be a very complete record of the total environment in which the facility is to be built. The black and white reproduction as shown in Figure 14 would also be effective in showing the soils and the environment. The designer and the contractor could use the mosaic map effectively to design the facility and construct it with minimal effect on the environment.



MARTINSVILLE SEGMENT 2.2.2 (C)

FIGURE 14. MASTER ENGINEERING SOIL PLAN.

A less effective master soil plan could be prepared from black and white aerial photographs in the scale range of 600 to 400 feet per inch. The mosaic strip map would be laid down as enlargements at a scale of 200 feet per inch. The enlargement could be copied and reproduced directly on the sensitized plan portion of standard plan-profile format. Since gray tones are recorded, the centerline stations should be flagged with either black or white material depending upon the ground surface.

The master engineering soil maps proposed will be very effective if local relief is low. A hill 200 feet high located two inches from the photo center on the 200 foot per inch aerial photograph would be displaced outward from true position about one-third of an inch. Each hundred feet of relief produces a distortion of one-twelfth inch at one-inch radius, one-sixth inch at two-inch radius and one-fourth inch at three inch radius from the photographic center. If these values are not acceptable then a higher altitude could be used. Doubling the altitude reduces the above displacements to one-half the amount. For large scale mapping at 600 feet per inch, the limiting altitude using a color corrected camera with a 6-inch focal length is 3600 feet; $8\frac{1}{4}$ inch focal length 4950 feet, and 12-inch focal length 7200 feet above average ground elevation. It is believed that few 12-inch cameras have been developed that have a lens suitable for color photography; probably few $8\frac{1}{4}$-inch cameras exist for this purpose. The distortions of the 6-inch, wide-angle, camera will therefore be acceptable or color orthophoto maps must be prepared. Orthophoto maps may be and usually are prepared in a black and white format.

Where significant local relief differences occur the master soil plan may be produced as a photogrammetrically prepared line map at a scale of 200 or 100 feet per inch. The scale is controlled by the Civil Engineer specifying the camera system for local conditions. The line map could be a five to ten diameter projection of the photographic scale depending upon type of photogrammetric plotter. For example, a double projection plotter equipped with stereo-image alternators could produce from color aerial photography an accurate master soil plan at a five diameter enlargement. The color aerial photographs could be obtained at an average scale of 1000 (or 500) feet per inch and the photogrammetric line map would be prepared at 200 (or 100) feet per inch. The accurate line map showing soil areas in plan view would be a part of the construction plans but it would not be as complete a master soil plan as contained on a color (or black and white) aerial photographic mosaic at the same scale. The aerial mosaic in any form contains inaccuracies in position.

Annotated color aerial photographs in the form of a strip map could serve as the master soil plan in areas of high relief if the user recognizes that the plan view is a simulation of the terrain. No aerial photograph is an exact analogue of the earth. The aerial photograph is an excellent simulation. In areas of very low local relief and with proper scaling the photograph approaches a true model of the earth's surface. The orthophoto although adjusted for relief and scale differences is still a simulation of the terrain. In areas of high relief, the orthophoto is probably the best type of background for the annotation of soil borders.

The map unit shown on a large scale master soil plan should be:

a. capable of a written definition to include land form type, parent material type, soil textural size or rock type, surface drainage condition, internal drainage condition, range in depth to bedrock and relative position of the water table in the spring period.

b. significantly different from other units either in land form type, topographic position within a specific land form, or textural size.

c. based on maximum utility for the type of project involved and at level of investigation such as preliminary location, design, or construction.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are based on the comprehensive studies by Rib (9) and Tanguay (11) that were performed within the relief situation and environment of the State of Indiana. Detailed conclusions are contained in the specific reports.

1. The most complete source for extraction of information on engineering soils and soil conditions by inference techniques is time lapse (stereoscopic) color aerial photography obtained in the spring period.
2. The second best source of information is black and white aerial photography.
3. The most versatile film type is the color negative type as both color and black and white positive prints can be prepared for airphoto interpretation of engineering soils.

4. The color aerial photographs should normally be flown at the same scale as the final color mosaic used for the master soil plan. This is true for preliminary surveys as well as detailed surveys. Enlargements can be made but the cost may be too excessive.
5. The master soil plan developed on a color mosaic strip map should be prepared at a scale factor of 200 feet per inch (1/2400) in areas of low relief. In areas of high relief, only preliminary engineering soil plans at photographic scales of 400 (1/4800) to 1000 (1/12000) feet per inch are practical depending upon relief conditions.
6. Infrared photography, infrared imagery, RADAR imagery and multichannel imagery may complement color or black and white aerial photography only a limited extent for engineering soils mapping. No quantitative information on soils or soil conditions is obtained by these systems.
7. Multichannel imagery lends itself to automatic mapping by use of a computer to statistically classify surfaces of reflectance. Soil surfaces are only a very small percentage of the total environment; therefore, the application to practical highway design projects is very limited. Only limited knowledge is available relative to significance of soil reflectance values pertaining to engineering soil parameters for design considerations.

It is recommended that research be performed to apply a number system to classification of topographic form, drainage form, erosional form and man-made forms similar to the number values used in reflectance

or emission as obtained by multiband sensor systems. A systems analysis approach to terrain evaluation might then be developed whereby the computer could be used more effectively to determine problem soil or design areas.

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